

# INVESTIGATION OF CLOUD PROPERTIES AND ATMOSPHERIC STABILITY WITH MODIS

## QUARTERLY REPORT FOR JUL-SEP 1996

Paul Menzel, Steve Ackerman, Chris Moeller, Liam Gumley, Kathy Strabala,  
Richard Frey, Elaine Prins, Dan LaPorte and Mervyn Lynch  
CIMSS at the University of Wisconsin  
Contract NAS5-31367

### ABSTRACT

The third quarter of 1996 was spent completing the Version 1 science software deliveries. All five production code packages have now been transferred to the Science Data Support Team (SDST) for integration into the Distributed Active Archive Center (DAAC). Considerable effort went into evaluating the infrared calibration of MODIS with the MODIS Characterization Support Team (MCST), including hosting an August audit of the calibration algorithm. All UW Algorithm Theoretical Basis Documents (ATBD's) were updated and distributed in preparation for the November panel review. Selected MAS data sets from the SUCCESS field experiment have been processed; early science results have identified wave clouds with very large spectral signatures in the infrared.

### TASK OBJECTIVES

#### Software Development

All five UW science production software packages (cloud mask, cloud top properties, cloud phase, atmospheric profiles, and ancillary data) have been delivered to SDST. Software development in the final quarter of 1996 will concentrate on refining the science portion of the algorithms.

#### ATBD Evolution

All UW ATBD's (cloud mask ATBD-MOD-06, cloud top properties and cloud phase ATBD-MOD-04, and atmospheric profiles ATBD-MOD-07) have been updated to reflect the current production software algorithms. The documents have been made available over the WWW in preparation for the November ATBD review.

#### MODIS Infrared Calibration

The theoretical development of the thermal IR calibration algorithm has been progressed as far as necessary; the possible non-isotropic nature of the background radiation is

incorporated very well. The algorithm is mature enough for software coding to begin at MCST.

## WORK ACCOMPLISHED

### MODIS Software Development

The final Version 1 production software packages, which generate standard at-launch MODIS products, were delivered to the SDST. The code for thermodynamic cloud phase, cloud top properties and atmospheric profiles were transferred and accepted by configuration management. The completion of the UW Version 1 production code deliveries represents the final step in a long progression of development involving everything from toolkit installations to visualization tools. Most of this work has been outlined in previous progress reports.

### HDF Cloud Mask Code

A new version of the MAS (MODIS Airborne Simulator) cloud mask has been written. It uses MAS radiance data input in HDF format, rather than McIDAS Digital Areas or simple binary “flat files”. Also, the HDF data sets contain more ancillary data than previously. There are now two identical versions of the cloud mask software (one at UW and another at GSFC) which will process both the UW McIDAS MAS and the DAAC HDF archived MAS data formats.

### Example Level 3 Products

CHAPS (Collocated **H**IRS and **A**VHRR **P**roduct**S**) data were used to simulate MODIS Level 3 data sets. Examples of global monthly mean and global 8-day mean gridded equal-area and equal-angle products at 0.5 degree spatial resolution were created in HDF-format. Both this data set and the HIRS cloud climatology cloud top properties data set are being used to develop Level 3 processing code for MODIS (see Figure 1).

### Shadow Detection

A first attempt has been made to detect cloud shadows using MAS multispectral radiance data. Reflectances from the 1.62, 0.88, and 0.66  $\mu\text{m}$  channels are used in a simple thresholding scheme to determine the presence of shadows over land surfaces. It is anticipated that modifications will be needed as MAS data from more land surface types becomes available.

### MODIS IR Calibration and Performance testing

MCST presented the MODIS IR calibration algorithm and thermal vacuum test data issues were discussed at the MODIS calibration workshop held in Madison, WI August 28-29. Some details that emerged were: (a) linear versus non-linear application of the calibration algorithm will be determined for each detector (instead of each band); (b) no image restoration should be applied in the IR; (c) blackbody thermistor processing will be done in two steps; first screening for bad data in each thermistor, and then screening for bad thermistors; (d) blackbody emissivity will be characterized and set pre-launch; any necessary postlaunch adjustments will focus on the BB temperature; (e) several elements in the cavity will be included in the background radiation term ( $L_o$ ) so that their radiation can be correlated with possible calibration errors postlaunch; (f) the algorithm will maintain an option for a floating detector patch temperature.

Further discussion lead to the following conclusions: Testing of the algorithm with data from the EM and PFM tests must begin as soon as possible. Software coding of the IR calibration algorithm should begin as soon as possible, in parallel with the testing of the algorithm with vacuum test data. The effects of the longwave infrared channel crosstalk must be characterized as completely as possible by SBRS, particularly the spatial weighting effects versus the spectral response effects. The importance of the spacecraft maneuver to view space must be stressed to the SWAMP scientist; the IR calibration is relying heavily on the data from this maneuver to characterize IR calibration dependence on scan angle.

Chris Moeller participated in the Santa Barbara Remote Sensing (SBRS) Quarterly Review at GSFC and the follow-up meeting (also Dan LaPorte, Merv Lynch) in September. During the review, MODIS Proto-Flight Model (PFM) performance test data were presented by SBRS. Performance anomalies in Long Wave Infrared (LWIR) bands are being evaluated in terms of impact on MODIS Cloud Properties, Atmospheric Profiles, and Cloud Mask Products. Sensitivity tests show that MODIS band 33-36 calibration error exceeds  $1^{\circ}\text{C}$  because of LWIR crosstalk and poor LWIR Relative Spectral Response (RSR) characterization (because of poor S/N in the test data). Concerns and recommendations have been forwarded to SBRS. A proposed modified MODIS performance test schedule includes further RSR characterization with improvement expected in the S/N of the LWIR RSR measurement, dry air purge (to remove water vapor) of the path from Spectral Measurement Assembly (SpMA) to MODIS PFM, and analysis of Point Spread Function and Out of Band Dispersive test data for spatial and spectral characterization of LWIR crosstalk from band 31 into bands 32-36. Accurate (within  $1^{\circ}\text{C}$ ) scan mirror temperature monitoring was also emphasized as a critical component of MODIS infrared calibration.

#### MAS Infrared Calibration

MAS spectral characterization has been measured at the Ames Research Center (ARC) calibration facility September 23,24. Measurement highlights include: (a) FTIR reference detector was installed and measurements were made for MAS Ports 2, 3, & 4. (b) The spectral leaks in Bands 38, 39, 40, & 41 were quantified. (c) The effect of water vapor on the spectral shape of bands 37 through 41 was removed. (d) The effect of CO<sub>2</sub> on the spectral shape of bands 34,49 & 50 was removed. (e) A procedure for rapid measurements of spectral band shape was implemented so that ports 2, 3, & 4 can be measured in less than 3 hours.

During a July visit to BOMEM in Quebec, Dan LaPorte suggested that BOMEM develop a larger source for the MB100 used at the ARC calibration facility. This would cause the source to effectively overfill the MAS aperture during spectral response measurement, eliminating a source of uncertainty in the spectral measurement. BOMEM has agreed to develop and ship a larger replacement source to ARC.

MAS post processed spectral response data were reviewed for application to the SCAR-B MAS data set (from August 95). Using atmospheric window spectral channels, a comparison between July 95 and October 95 spectral measurements showed a spectral shift in Port 1 (VIS,NIR) of about .002 microns, in Port 2 (SWIR) about .006 microns, in Port 3 (MWIR) about .035 microns, and in Port 4 (LWIR) about .015 microns. All shifts were to shorter wavelengths. These shifts represent 5%, 12%, 23%, and 3% of the typical spectral bandpass in Ports 1-4 respectively. This comparison is used to characterize the MAS spectral performance during SCAR-B. The updated MAS spectral response has been delivered by ARC to the GSFC DAAC for SCAR-B data set processing.

A disagreement between MAS HDF infrared radiances (produced at GSFC DAAC) and University Wisconsin MAS McIDAS radiances was found during comparison testing. The disagreement was traced to a coding error in the GSFC processing software and has been rectified for Version 6 processing. Routine parallel testing is recommended to minimize impact of other future processing errors.

MAS blackbody effective emissivity estimates and their impact on IR calibration were presented in the EOS conference at the SPIE annual meeting held in August. Results of that work show that MAS infrared calibration biases (compared to HIS instrument) are less than 1°C for LWIR channels and show minimal dependence on scene temperature. Further comparisons of MAS calibrated radiances with HIS radiances are planned on a deployment by deployment basis.

#### GOES Biomass Burning Program

A number of GOES-8 data sets were collected in North and South America during the past burning season. Diurnal (3-hourly) GOES-8 multispectral data were collected in

real-time for the 1996 biomass burning season in South America (June-October). The data will be processed with the GOES-8 ABBA to continue monitoring trends in biomass burning and to catalogue the extent and transport of associated aerosols. In North America CIMSS participated in a multi-sensor early warning fire detection assessment study in New Mexico (3-17 June 1996) and Alaska (24 June - 8 July 1996) under the direction of Dr. Chris Elvidge at the NOAA National Geophysical Data Center. Half-hourly multispectral GOES-8 data were collected for two weeks in each study region. A version of the current GOES-8/9 ABBA used in South America will be used to produce diurnal GOES ABBA products for specific case studies in New Mexico and Alaska. Half-hourly GOES-8 data as well as diurnal NLDN lightning data were collected during the first two weeks of September over the continental US. In addition a series of 1-minute multispectral super rapid scan GOES-9 data were collected over the Western US on 16 August and 5 September 1996. These data sets will aid in the development of an operational GOES-8/9 ABBA for the continental US.

A revised version of the GOES-8 ABBA is being used to process GOES-8 multispectral data for the 1995 SCAR-B field program. The revised GOES-8 ABBA includes an improved variable offset for the short and longwave infrared windows to correct for the attenuation due to non-opaque clouds that often form directly over the fire. The revised ABBA also contains adjustments for diffraction in the 4 and 11 micron bands. The SCAR-B GOES-8 ABBA results will be presented at the SCAR-B Science Symposium in Fortaleza, Brazil (4-8 November, 1996).

This work is supported by separate NASA and NOAA contracts.

### Aerosol Detection

Hourly multi-spectral GOES-8 data were collected over the eastern US and the Atlantic Ocean during the TARFOX field campaign (10-31 July 1996). The GOES satellite database for this study extends from 10 to 60°N and from 20 to 100°W. During ER-2 flights half-hourly GOES imagery were collected. These data will be used in conjunction with SCAR-B GOES, ancillary aircraft, and ground measurements to document the spatial and temporal distribution of aerosols over the Atlantic Basin. This work is part of a collaborative effort led by Mr. Brent Holben (NASA/GSFC) to characterize aerosol forcing over the Atlantic Basin associated with three major aerosol components in this region: urban/sulfate, Saharan dust, and biomass burning.

### Preparation for the WINter Cloud Experiment (WINCE)

Preparations are underway for the January/February 1997 WINCE field program to be based in Madison, WI. WINCE will assess cloud and snow detection in winter background conditions (snow,ice) in support of MODIS data products (MODIS Cloud Mask, Cloud Top Properties, Snow Mask). The experiment will be conducted using

NASA's ER-2 aircraft with a projected payload including MAS, HIS, MIR, CLS and TSCC. A field site visit headed by Gary Shelton (NASA HQ) has confirmed the utility of Truax Field for supporting the ER-2 aircraft operations. MAS will provide multispectral observations of clouds and snow background conditions; CLS will provide cloud detection validation; HIS will provide IR calibration validation as well as spectral data for atmospheric profiling and cloud studies, while MIR collects microwave observations. Data collection will take place over the upper Midwest and Southern Canada in both day and nighttime conditions.

## DATA ANALYSIS

### HIRS Cloud Climatology

Seven years of HIRS data have now been processed using the CO<sub>2</sub> slicing cloud top property algorithm. Overall, cirrus clouds have shown a slow increase from 1989 to 1996 of about 1 percent per year. Over the globe, cirrus clouds are now observed at about 40% of the time. Figure 1 shows the geographical distribution of cirrus clouds in the summer and winter seasons (darker regions indicate more frequent cloud occurrence). The months of December, January and February were summarized for the boreal winter (austral summer) and the months of June, July and August were used for the boreal summer (austral winter). The seasonal summaries were compiled using a uniformly spaced grid of 2 degree latitude by 3 degree longitude. Each grid box for each season has at least 1000 observations. Global circulation patterns are evident. The Inter-Tropical Convergence Zone (ITCZ) stands out as an area of increased probability of cirrus near the equator shifting north during the boreal summer. Sub-tropical highs associated with subsidence can be identified by the lower probabilities of cirrus (0-20%) areas surrounding the ITCZ. These areas also follow the sun, moving north during the boreal summer. Asian monsoon regions (e.g. India) appear covered by > 60% probability of cirrus during the boreal summer; this value falls to less than 40% during the boreal winter. Extra-tropical storm belts can be found in the mid and upper level latitudes of both hemispheres where there is a higher probability of cirrus. This probability increases during the respective winter months. Large convective development occurs during the austral summer in South America and Africa, which is readily apparent in the increased occurrence of high cirrus clouds. These patterns are very similar to those observed in the four year summary (Wylie et al., 1994).

Figure 1 shows the HIRS derived seven year average distribution of cirrus clouds in the winter and summer seasons; it is a Level 3 product which will also be generated from MODIS data.

### Early SUCCESS Field Program Results

MAS flew 18 missions on the ER-2 aircraft during the SUCCESS field experiment. The data set quality is excellent. Investigations to date have focused primarily on cloud studies (microphysical properties, cloud top pressure and emissivity). Figure 2 is an example of a contrail captured in three MAS channels. Note how the contrail is barely visible in the .66 micron image, and yet appears bright (reflective) in the 1.88 micron channel and cold (dark) in the 11 micron channel image.

CO<sub>2</sub> cloud top heights are being investigated using MAS data with validation from the CLS (lidar) data. Two different approaches are being utilized in the cloud heights algorithm, the first utilizing brightness temperature gradient across a target box, while the

second relies on an estimate of clear air radiance from the MAS data. Thin cirrus scenes from the 26 April 1996 ER-2 flight are used. Results (Figure 3) show MAS cloud top heights are lower for both approaches than those given by CLS data, possibly because atmospheric conditions may not be well characterized. Of the two approaches, gradient method cloud heights exhibit more noise than clear air radiance cloud heights. This is probably due to increased sensitivity to instrument noise in the gradient approach; when the brightness temperature gradient in the target box is small (e.g. uniform cloudy target box), then the resulting cloud height is influenced by radiometric noise. Clear air radiance results are more uniform spatially and show trends that agree with the CLS cloud heights. Very thin cirrus scenes from 19.72 hrs to 19.76 hrs are not detected by the MAS CO<sub>2</sub> slicing algorithm. Further investigation into MAS CO<sub>2</sub> cloud heights is planned. Regarding cloud microphysical properties, anomalously large MAS T<sub>11</sub>-T<sub>12</sub> and T<sub>8</sub>-T<sub>11</sub> brightness temperature differences have been found in wave cloud and aircraft contrail scenes. Theory suggests large brightness temperature differences occur when effective cloud particle size is small; the MAS observations parallel the theory. These observations suggest an importance of small particle size clouds to earth system radiative budget studies.

## PAPERS

Menzel, W.P., and E.M. Prins, 1996: Monitoring biomass burning and aerosol loading and transport utilizing multispectral GOES-8 data. Paper presented at the 1996 International Symposium on Optical Science, Engineering, and Instrumentation, Denver, CO, August 4-9, 1996.

Moeller, C. C., P. S. Grant, D. D. LaPorte, L. E. Gumley, P. Hajek, W. P. Menzel, J. S. Myers, and S. White, 1996: Blackbody emissivity considerations for radiometric calibration of the MODIS Airborne Simulator (MAS) thermal channels. Presented at the Earth Observing System Conference of the SPIE Annual Meeting, August 4-9, Denver, Colorado. Proceedings pending.

W. P. Menzel, D. P. Wylie and K. I. Strabala, 1996: Seven years of global cirrus cloud statistics using HIRS. Presented at the International Radiation Symposium, August 19-24, Fairbanks, Alaska.

Ackerman, S. A., 1996: Monitoring the Antarctic radiation inversion using satellite measurements at 11 and 6.7  $\mu\text{m}$ . Presented at the International Radiation Symposium, August 19-24, Fairbanks Alaska.

Smith, W. L., S. A. Ackerman, H. Revercomb, H. Huang, W. Feltz, L. Gumley, A. Collard and J. Spinhirne, 1996: High spectral resolution infrared remote sensing - Spectral



infrared radiative absorption properties of nearly invisible high altitude ice crystal clouds. Presented at the International Radiation Symposium, August 19-24, Fairbanks Alaska.

H. E. Revercomb, M. J. Lynch, K. I. Strabala, L. E. Gumley and P. F. Van Delst: Land surface temperature and emissivity estimation with high spectral/high spatial resolution sensors. Presented at the International Land Surface Temperature Workshop, September 16-20, at the University of California - Santa Barbara.

## MEETINGS

Dan LaPorte worked with BOMEM personnel in Quebec to develop a larger source for the MB100 to improve MAS spectral calibration in July.

Paul Menzel, Steve Ackerman, Liam Gumley, Chris Moeller and Merv Lynch attend the Atmosphere Group Discipline Meeting at Chincoteague, Virginia on July 17 and 18.

Paul Menzel, Steve Ackerman and Kathy Strabala attended a cloud mask meeting hosted by Bryan Baum of LaRC on July 19.

Paul Menzel and Steve Ackerman were presenters at the International Radiation Symposium in Fairbanks, Alaska on August 19-24.

Elaine Prins attended the Multi-sensor Early Warning Fire Assessment Workshop (24-25 August, 1996) at the NOAA National Geophysical Data Center in Boulder, Colorado. She presented an overview of the UW-Madison CIMSS GOES fire detection program.

The UW hosted the infrared calibration audit for the MCST August 29 and 30.

Kathy Strabala attended the Science Advisory Panel Meeting held at GSFC on September 4 and 5. P. Menzel attended on the second day.

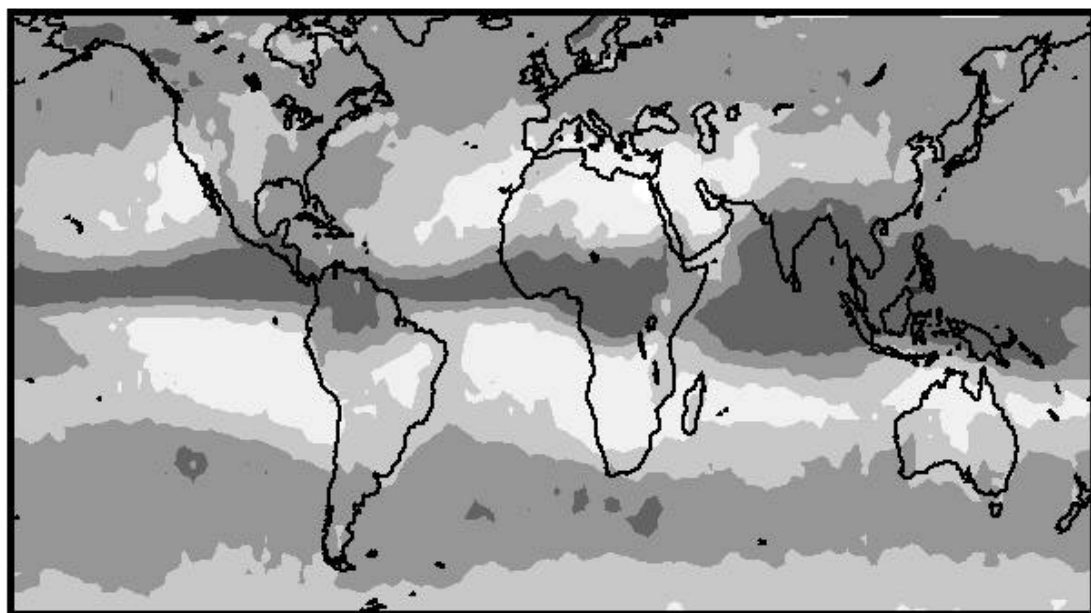
Mervyn Lynch was a presenter at the International Land Surface Temperature Workshop held at the University of California - Santa Barbara on September 16 - 20.

Chris Moeller attended the SBRS quarterly review meeting at GSFC on September 18 and 19.

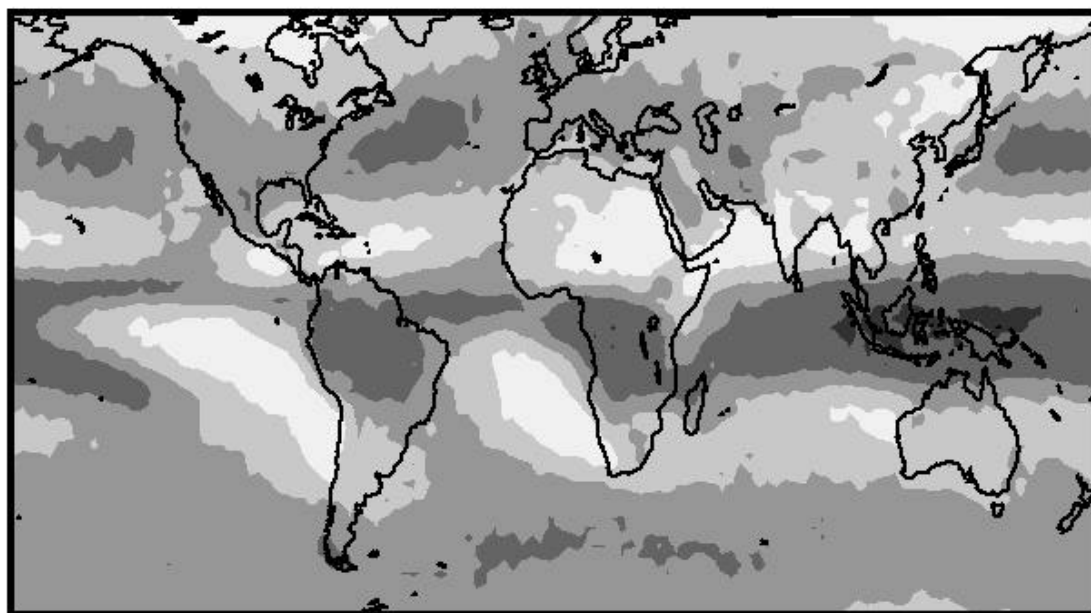
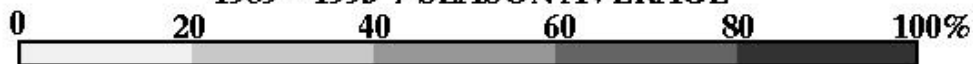
Dan LaPorte assisted with MAS Spectral Calibration work at Ames Research Center September 23 and 24.

Dan LaPorte, Chris Moeller and Merv Lynch participated in a 4 hour telecom chaired by MCST personnel concerning MODIS Proto-flight test results on September 23.





**HIRS PROBABILITY OF CIRRUS JUN-AUG**  
**1989 - 1995 7 SEASON AVERAGE**



**HIRS PROBABILITY OF CIRRUS DEC-FEB**  
**1989-1995 7 SEASON AVERAGE**

Figure 1. Geographical distribution of cirrus clouds in the summer and winter seasons from June 1989 through May 1996 (darker regions indicate more frequent cloud occurrence). The months of December, January, and February were summarized for the boreal winter (austral summer) and the months of June, July, and August were used for the boreal summer (austral winter).

MAS 0.66 micron 04/20/1996 15:56:05 UTC  
Gain Corrected Counts (Histogram Equalized)



MAS 1.88 micron 04/20/1996 15:56:05 UTC  
Gain Corrected Counts (Histogram Equalized)



MAS 10.98 micron 04/20/1996 15:56:05 UTC  
Gain Corrected Counts (Histogram Equalized)



Figure 2. Three spectral images observed by the MAS instrument 20 April 1996. Note the contrail which appears bright (reflective) in the 1.88 micron image and cold (dark) in the 11 micron image, but appears very faint in the .66 micron image.

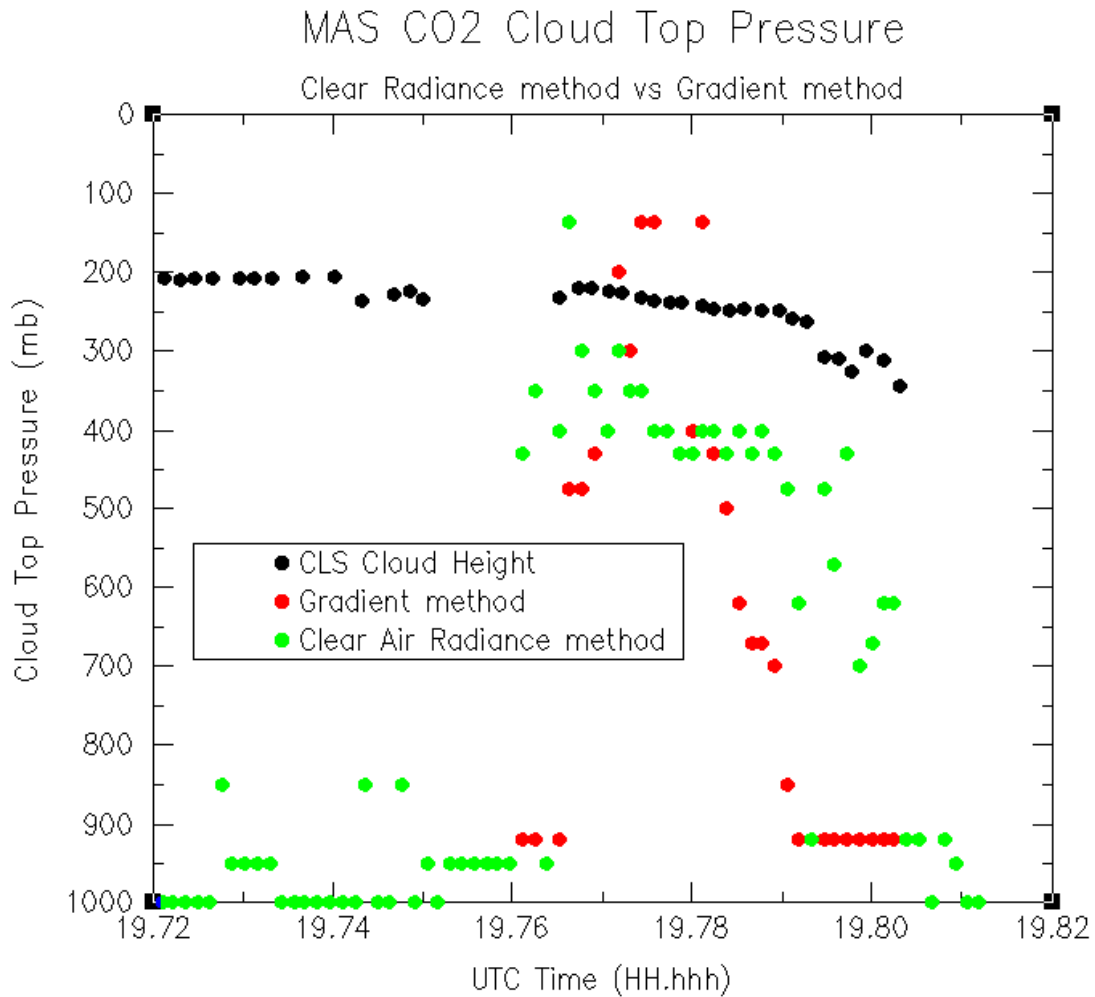


Figure 3. MAS CO<sub>2</sub> cloud top pressure estimates on April 26, 1996 over Kansas. Cloud top pressure from CLS lidar also shown as validation. MAS CO<sub>2</sub> algorithm tracks relative variation of cloud top pressure. Very thin cirrus cloud is unresolved in MAS data before 19.76 UTC.